Theory II: transport and mechanics

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Outline

1. Nanoelectromechanical devices
   (J.K., S. Viefers, T. Johansson [M.Sc. Thesis])
2. Nanotube SET
   (J.K., Jaeuk Kim, Ilya Krive)
3. Other projects
   (Andreas Hall [M.Sc. thesis], Elisabetta Inglessi
   [M.Sc. thesis])

Nanoelectromechanical devices

- Discrete charge redistribution on the nanometer scale creates large Coulomb forces
- Electronic transport is highly sensitive to mechanical deformations

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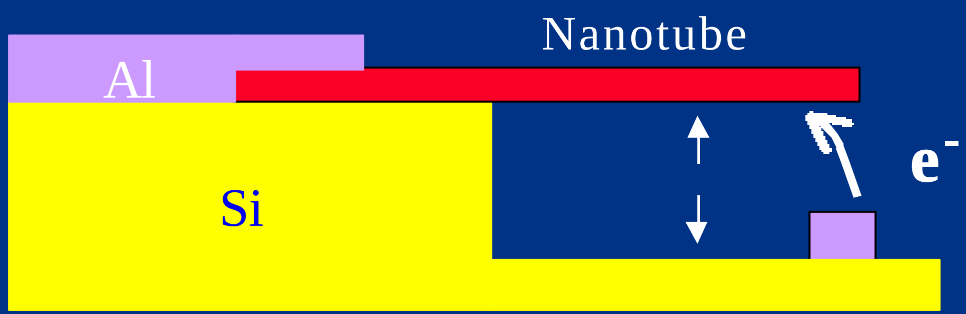
Nanorelay (2-terminal)



$$\tau_R = RC \sim 10^{-11} - 10^{-12}\ s$$

$$\tau_{elastic} \sim 10^{-11} - 10^{-12}\ s$$

Tunnel junction with dynamically varying geometry

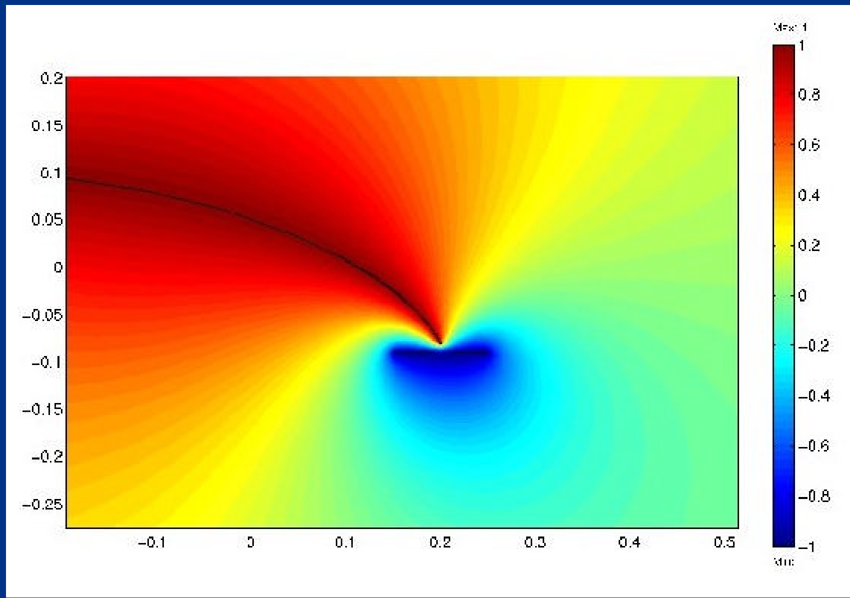
$\Rightarrow$variable tunneling resistance and capacitance:

(x = tube displacement, h = maximum displacement)

$R_T(x) = R_T(x=h)\exp[-\alpha(h-x)]$

$C(x) \approx C(x=h)/(d-x)$ (*determined numerically*)

Additional parameters: tube length, contact resistance,...



Methods:

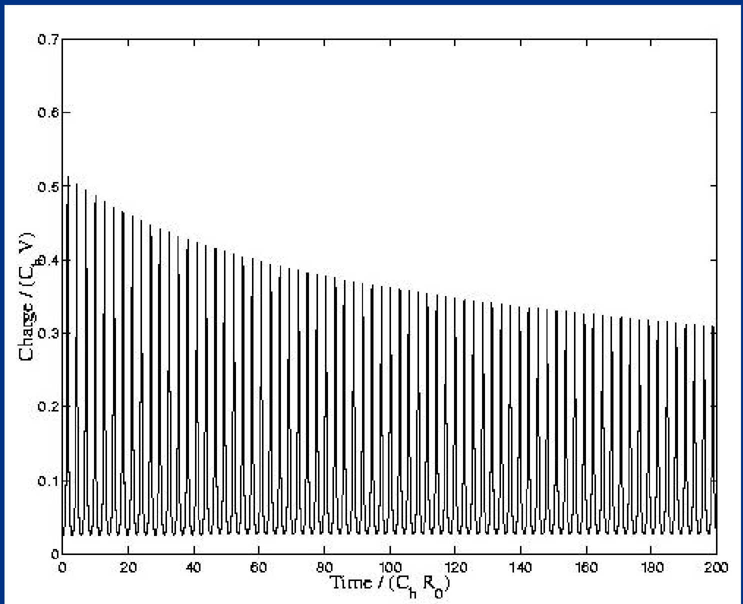
1. Classical circuit analysis (*large tunneling current limit*)
   - mechanical motion described using classical elasticity theory
   - charge granularity and electron correlations ignored
2. Stochastic tunneling analysis
   - mechanical motion described using classical elasticity theory
   - electron correlations ignored
3. Microscopic model
   - mechanical motion described by a single harmonic oscillator
   - damping ignored, tube approximated as a semi-infinite LL

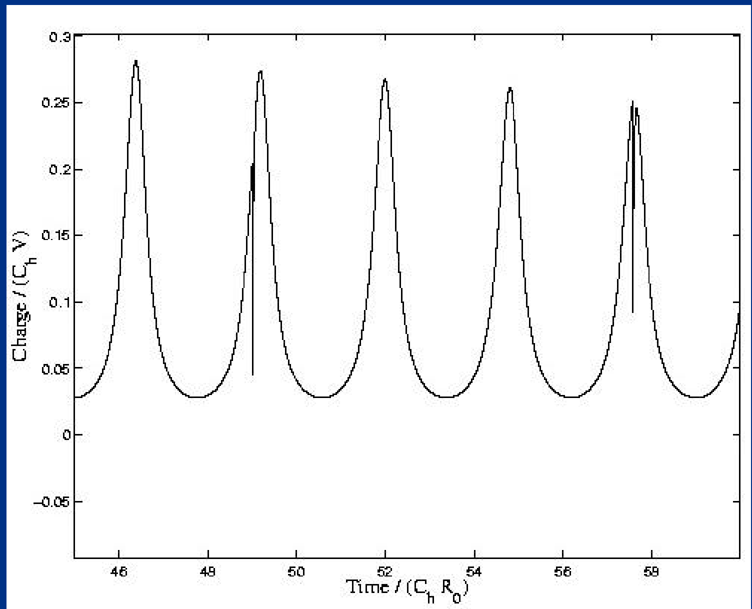
Results:

- realistic values for the contact resistance lead to significant damping

- for realistic parameters, the effect of electron tunneling on tube motion (*the kick-back effect*) is small

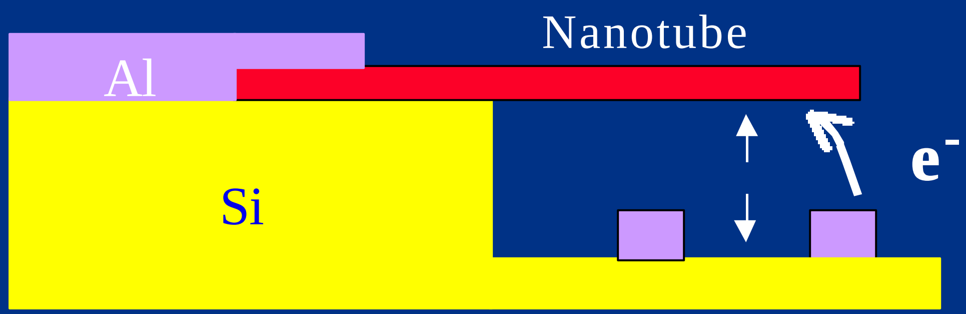
- the microscopic model leads to a modified Tien-Gordon model for phonon-assisted tunneling





What next:

3-terminal device



- device geometry controlled by gate voltage
- allows for small source-drain voltages, and small power consumption
- study switching characteristics and damping

Nanotube SET

<u>Experiment:</u>

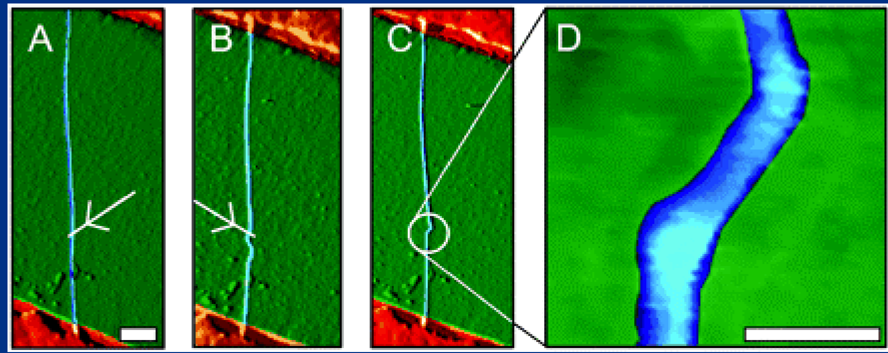
H. W. Ch. Postma, T. Teepen, Z. Yao, M. Grifoni, and C. Dekker, Science 293, 76 (2001)

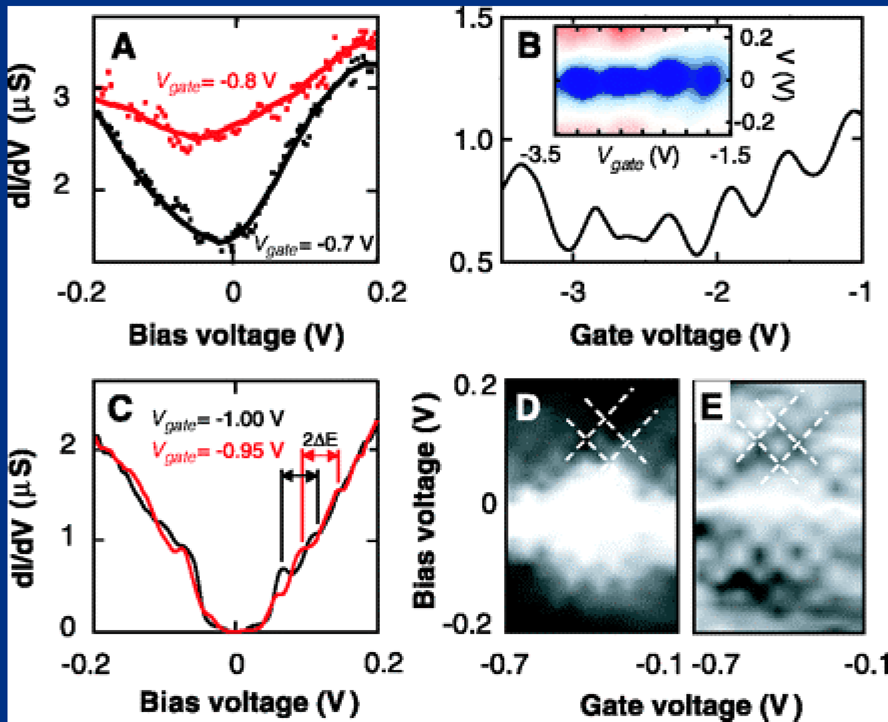
<u>Theory:</u>

- developed for uncorrelated systems
- a T=0, V=0 theory exists for correlated systems

<u>Our approach:</u>

- sequential tunneling through a finite LL segment
- finite T and V
- analytic calculation of tunneling rates (*finished*), numerical solution of master equation





Other projects

Magnetic field effects on nanotubes
- A. Hall, M.Sc. thesis
- transverse magnetic field induces a gap in metallic zigzag tubes (3n,0)

Transport measurements in carbon nanotubes
- E. Inglessi, M.Sc. thesis (NPL, London)
- focused on AFM manipulation of tubes